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That Nice "Woodsy" Smell

Combustion Spillage From Residential Wood Heating Systems

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Abstract

Previous studies have shown that woodburning systems may release smoke into dwellings under certain conditions. These pollutants are known carcinogens which may pose a risk to the health of the inhabitants if present in high concentrations or in moderate concentrations over an extended period of time. A study of 100 randomly selected wood heating systems across Canada was conducted to determine the condition of the systems, and the householders were interviewed to establish the frequency, duration and severity of smoke spillage incidents. A further 35 systems were targeted for field monitoring to establish the mechanisms of smoke spillage from troubled woodburning systems. Laboratory testing investigated appliance-related causes of combustion spillage and other specific mechanisms that may contribute to spillage. Remedial measures to increase the spillage resistance of wood heating systems were tested and the results presented. The research demonstrated that spillage can be prevented through good system design, component selection, and proper appliance operation and maintenance.

Key Words: wood stoves, indoor air pollution, combustion spillage, backdraft

Disclaimer

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Executive Summary

That Nice "Woodsy" Smell

Interviewer: "Does your woodburning appliance smoke?"
Householder: "No."
Interviewer: "Then let me ask you this: when the appliance is operating, have you ever noticed a nice woodsy smell in the house?"
Householder: "Yes, and we love it. It's one of the things we enjoy about burning wood."

The title of this report reflects one of the key findings of CMHC's research into combustion spillage from woodburning systems. Unlike heating systems that use conventional fuels such as oil and gas, the effective performance of woodburning systems is strongly influenced by the way they are operated and how sensitive the users are to the smell of smoke in the house. *That Nice "Woodsy" Smell* was selected as the title to draw attention to the importance of the 'human factor' in the reduction of indoor air pollution related to woodburning systems. It also highlights the common acceptance of wood smoke as a benign pleasant smell, even though it is composed of a number of known and suspected carcinogens.

Previous research conducted for Canada Mortgage and Housing Corporation (CMHC) revealed that fireplaces commonly spill combustion products into living spaces. Subsequent work showed that factory-built fireplaces with doors consume less air and are less susceptible to spillage during episodes of moderate house depressurization than anticipated. This study was designed to extend the work to include wood-fired heating appliances such as space heaters, cooking ranges, fireplace inserts and central heating systems.

In order to establish the frequency and severity of spillage events from existing systems, 100 householders across Canada were interviewed and their wood heating systems were inspected by qualified technicians. Although 97 of the systems had some history of spillage, about half of the spillage episodes were minor and could easily be controlled by the user. The most common form of spillage occurs when the appliance loading door is opened for fire kindling or reloading; 85 users reported open door spillage. Closed door spillage is considered more serious and was reported by 30 of the users that were interviewed. About 10 percent of the systems were severely troubled and would require significant re-design and component replacement to correct the problems.

Analysis of the survey data revealed links between system characteristics and spillage type and frequency. For example, systems with long flue pipe assemblies and those with more than one elbow were more likely to spill when the loading door is opened than systems with short flue pipes and no elbows or one elbow. Systems with chimneys running up the outside of the building were somewhat more likely to

experience open door spillage. Appliances with manually-operated, internal by-pass dampers, those with bi-metallic combustion air control operators, and systems with flue pipe key dampers were all more likely to experience closed door spillage. The statistical incidence of spillage-inducing characteristics was much higher in the severely troubled systems than in the rest of the sample.

One of the significant findings from the survey was the importance of user input to the performance of the systems. Systems which appeared "perfect" from a spillage resistance point of view would spill because of the way they were operated, and systems with several characteristics that should make them susceptible to spillage did not spill because of careful and knowledgeable operation by the user. The survey data indicated that in about 50 percent of all spillage reported, the influence of the user was a primary factor, and it appears to be a contributing factor in a large majority of all spillage problems.

A total of 34 systems were field tested at various levels of detail, from fully instrumented monitoring, to inspection and homeowner discussion only. A number of remedial measures that could be expected to reduce the likelihood of spillage were developed and tested while the instrumented systems were monitored to observe changes in performance. In general, the remedial measures were designed to achieve two objectives: reducing restrictions, or other factors adverse to the flow of combustion gases, and raising the average flue gas temperature throughout the system. Most of the remedial initiatives were highly successful and spillage was eliminated completely. Spillage related to severe house depressurization caused by powerful exhaust ventilators such as kitchen exhausts and exhaust-only house ventilators could not be eliminated by changes to the woodburning system. In these cases, changes to the ventilation system or the installation of a whole-house make-up air system would be required.

Laboratory testing was carried out to assess the degree to which appliance design affects sensitivity to spillage. The research showed that some appliance design characteristics increase the likelihood of spillage. These characteristics include large loading doors relative to flue collar area, flue collars located at or below the top of the loading door opening, and internal restrictions to gas flow such as small exhaust passages. It is concluded that appliance manufacturers should consider spillage sensitivity as part of their product design strategy. A test methodology for assessing spillage sensitivity is proposed in the report.

Appliances meeting the requirements of the U.S. Environmental Protection Agency (EPA) emissions regulation appear less likely to have closed door spillage compared to conventional appliances because of their ability to maintain stable flue gas temperatures, even at relatively low firing rates.

The research revealed that spillage is normally caused by a combination of factors, including operator inputs, system design and external influences such as weather. To be successful, therefore, the diagnosis and remedial strategy to correct spillage problems must address the full range of possible contributing factors.

1. Introduction

There are 369,000 households in Canada that consider wood as their primary energy source for home heating. A further one million households use wood as a supplementary energy source in addition to a conventional source[1]. Together, the primary and supplementary users of wood fuel represent over 20 percent of all single family dwellings in Canada. Wood fuel is a significant contributor to residential space heating requirements; conservative estimates suggest that it displaces on the order of half a billion dollars of conventional energy supplies annually.

Throughout the 1980s, Canada Mortgage and Housing Corporation (CMHC) has been the focal point in Canada for research into the mechanisms of venting failure in residential combustion systems using oil, gas and wood as fuel. Venting failure results in the spillage of part or all of the products of combustion into living spaces. Since some components of wood smoke are suspected carcinogens, combustion spillage from woodburning systems is viewed as a potential health risk for people who live with troubled wood heating systems.

In the area of woodburning, CMHC has studied venting failure in fireplaces[2] (mostly masonry), and a laboratory research project on the dynamics of airflows through factory-built fireplaces[3]. Initial surveys revealed that a substantial proportion of existing fireplaces experience some degree of spillage. Subsequent laboratory work demonstrated that glass door assemblies, even those that are not gasketed and relatively leaky, increased the resistance to spillage. The work also demonstrated that the combustion air consumption of fireplaces with gasketed doors and controllable air supplies is relatively low and probably would not cause significant depressurization of houses. Finally, this work demonstrated that make-up type outdoor air supplies are ineffective and that outdoor air supplies directly ducted to the combustion chamber may be effective but can reverse flow direction in certain circumstances, leading to the overheating of combustibles adjacent to the duct.

These projects have served to demonstrate some mechanisms of venting failure not previously understood and have provided new insights into the ways in which houses and woodburning systems interact. While CMHC's work added greatly to the understanding of venting failure in woodburning fireplaces, less was known about the frequency, severity and mechanisms of venting failure in woodburning heating appliances such as wood stoves, cooking ranges and central heating systems.

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[1] Statistics Canada Catalogue 64-202 Quarterly, Household Facilities and Equipment, 1989

[2] CMHC Report: Residential Combustion Venting Failure: A Systems Approach, Project 5: Remedial Measures for Woodburning Fireplaces, 1987

[3] CMHC Report: Fireplace Air Requirements, 1989

Terms of Reference

In order to extend the research to include the full range of standard Canadian heating systems, CMHC engaged Performance Woodburning Inc. and IRTA to explore and define the mechanisms of venting failure in residential woodheating systems and to test possible remedial measures which could be expected to increase the resistance of these systems to venting failure.

The following were the primary objectives for the project:

1) To develop a qualitative assessment of the existing inventory of residential woodburning systems in terms of system configuration and spillage frequency.
2) To define the system characteristics and external conditions which tend to result in spillage.
3) To propose remedial measures which will reduce the likelihood of spillage and to test these remedial measures through field testing and monitoring.
4) To gain insights into the degree to which user practices contribute to spillage events, to assess the mechanisms involved in user-induced spillage events, and to propose alternative practices which would result in fewer such events.

Methodology

The qualitative assessment involved a national survey/inspection of randomly selected wood heated houses and the analysis of the results. System characteristics and conditions which could be expected to result in spillage were defined through laboratory testing of sample appliance types, field testing of targeted systems and their correlation with the survey/inspection results. Proposed remedial measures were developed based on the survey/inspection, field testing and laboratory test results. After field monitoring of selected systems to establish as-found performance, the remedial measures were carried out and the systems were again monitored to identify any changes in performance. A more complete discussion of methodology is presented in the appendices.

2. How Widespread is Venting Failure?

Overview

One hundred randomly selected householders across Canada were interviewed and their wood heating systems inspected to assess the configuration and condition of the systems and to determine the frequency and severity of spillage events. Of the 100 homeowners interviewed, only four claimed that their system never spilled. However, a photograph of one of the four appliances showed obvious smoke staining above the loading door, indicating that a significant amount of spillage had occurred. The survey results demonstrated that almost all wood heating systems release combustion gases into the home to some extent.

Surveyed Spillage Events

The survey data were analyzed to identify trends in the type of spillage events and system characteristics that contribute to combustion spillage. Spillage events from the survey were separated into four categories in ascending order of severity, as follows:

1. Smells of any kind
2. Spillage when the loading door is open
3. Spillage when the loading door is closed
4. Spillage over night

Smells of Any Kind

The surveyor prompted for four smells:

- a faint woodsy smell - 51% reported
- a strong wood smoke smell - 31% reported
- the smell of hot steel - 9% reported
- the smell of creosote - 18% reported

Of the total of 100 surveys, 19 respondents reported no smells of any kind, but of these, 15 reported some smoking in the other categories. This category was considered the least serious form of spillage.

Spillage When the Loading Door is Open

This category of spillage was considered more serious than the smell category, but not immediately hazardous because it is assumed that when the loading door is open someone is present to manage the severity and duration of the spillage. The responses and relative frequency were:

- any door open smoking - 85%

- frequency: rarely - 44%
- frequency: occasionally - 29%
- frequency: often - 12%

Spillage When the Loading Door is Closed

Spillage that occurs when the loading door is closed is considered serious and implies that the system is failing in a significant way. The responses and relative frequency of occurrences were:

- any closed door spillage - 31%
- frequency: rarely - 19%
  occasionally - 11%
  often - 1%

Spillage Overnight

This is considered to be the most serious form of spillage because it could lead to injury or death of the occupants. Of the total sample, 9 respondents reported spillage events while the family was sleeping.

Although almost all the householders surveyed claimed that their wood heating systems spilled smoke into the house, the majority indicated that these episodes were infrequent and involved only minor amounts of smoke. About 30 percent of the surveyed systems exhibited significant spillage that occurred often enough to be of concern, and about 10 percent could be considered seriously troubled.

3. The Mechanisms of Venting Failure

Influence of System Design on Spillage Frequency

There are many system design elements and operating conditions which can be expected to cause or influence the spillage of combustion gases from woodburning systems. Most of the systems surveyed had a blend of spillage promoting and spillage resistant characteristics. For this reason, attempts to analyze the survey data on several of these parameters at once yielded no significant trends. However, when the individual system design elements from the surveyed households were analyzed, some trends began to emerge.

Flue Pipe Length and Open Door Spillage

In the survey sample, longer flue pipes were linked to more frequent open door spillage. Systems which spilled often when the door was open had almost twice as much total flue pipe length and more than three times as much horizontal flue pipe than systems for which no open door spillage was reported.

- never - averaged 105 cm (42") total flue pipe length, 28 cm (11") horizontal
- rarely - averaged 162 cm (65") total flue pipe length, 60 cm (24") horizontal
- occasionally - averaged 138 cm (55") total flue pipe length, 39 cm (16") horizontal
- often - averaged 201 cm (80") total flue pipe length, 108 cm (43") horizontal

Flue Pipe Elbows and Open Door Spillage

Systems that experienced open door spillage were about twice as likely to have either 45 or 90 degree elbows in the flue pipe than the systems which did not spill when the door was open. This finding can be attributed to the increased resistance and flue gas cooling that elbows can be expected to produce. The presence of 90 degree elbows in a flue pipe assembly implies that at least part of the assembly is horizontal, and this can also be expected to promote open door spillage.

How the Design of Flue Pipe Assemblies Affect Spillage

An average size woodstove operating at a moderate firing rate produces a flow velocity in its flue pipe on the order of 1 metre per second. At this low gas velocity, elbows and straight sections of pipe present little resistance to flow, far less resistance than that offered by the air control and internal combustion air passages. However, when the appliance loading door is opened, the gas velocity increases significantly, to as much as 2 metres per second, as dilution air flows through the door opening into the system. At this velocity the resistance to flow increases about three-fold for each 90 degree elbow and metre of flue pipe compared to the resistance at a flow of 1

metre per second[4]. For systems with only one metre of flue pipe and one 90 degree elbow, the pressure drop through the flue pipe assembly may total less than 1 Pa. But longer flue pipe assemblies with two or three 90 degree elbows could cause a pressure drop of 5 Pa or more, enough to be a primary factor in open door spillage. Note also that when the loading door is opened the location of the primary resistance in the system shifts from the air control, which is upstream of the fire, to the flue pipe assembly, which is downstream of the fire. These factors help to explain why, in the survey sample, flue pipe length and number of elbows did not show up as a significant factor in closed door spillage, but was a key factor in open door spillage. The analysis also highlights the importance of keeping the venting system clean in the prevention of open door spillage.

Inside/Outside Chimneys and Open Door Spillage

Some correlation was found between the frequency of open door spillage and whether the chimney was installed inside or outside the house envelope. Outside chimneys tend to produce lower average draft than inside chimneys because they are exposed to outside cold. Outside chimneys also force at least one elbow in the flue pipe assembly, and the base of the chimney represents another 90 degree change of flue gas direction.

- never spills - 40% were served by outside chimneys
- rarely spills - 50% were served by outside chimneys
- occasionally spills - 50% were served by outside chimneys
- spills often - 70% were served by outside chimneys

By-pass Dampers and Closed Door Spillage

Appliances with bypass dampers appear to be implicated in more closed door spillage events than appliances without such devices. Bypass dampers are designed into appliances which have internal restrictions to flue gas flow that would otherwise cause extreme spillage. The bypass damper is opened when a fire is to be started or the appliance is to be reloaded. Cooking ranges, catalytic appliances, sidedraft and downdraft appliance types, as well as restrictive updrafts[5] use bypass dampers. These internal restrictions could increase the likelihood of closed door spillage when chimney draft is low because of chimney cooling or fire smouldering.

- never spills - 17% had by-pass dampers
- rarely spills - 32% had by-pass dampers
- spills occasionally or often - 55% had by-pass dampers

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[4] Based in part on the ASHRAE Handbook of Fundamentals, Chapter 33: Duct Design

[5] See discussion of appliance design types, page 20

Bi-metallic Air Control Operators and Closed Door Spillage

In the random sample, appliances with bi-metallic combustion air control operators were slightly more likely to be associated with closed door spillage. Bi-metallic operators reduce the combustion air supply as the body of the appliance heats up. The intention is to automatically regulate the firing rate and heat output. However, when these controls are set slightly too low, they can close off the air supply almost completely, causing a lower-than-anticipated firing rate and the collapse of effective combustion. This inadvertent smothering of the fire can produce combustion oscillations, a form of closed door spillage in which the emission of smoke occurs in short, repeated puffs. Five of the ten systems whose users reported spillage in the form of puffing had appliances with bi-metallic air controls.

Flue Pipe Key Dampers and Closed Door Spillage

A slightly higher percentage of systems that experienced closed door spillage had flue pipe key dampers than those systems for which no spillage was reported. Some of the survey respondents admitted that spillage occurred when the damper was closed too much and had reduced the firing rate to a smoulder.

- 24% of those reporting no spillage had key dampers
- 35% of those reporting spillage had key dampers

The sample showed no correlation between outside chimneys and closed door spillage. In fact, more systems reporting no spillage had outside chimneys than inside.

Characteristics of Severely Troubled Systems

In order to simplify the analysis of survey data, a rating system was developed to reduce the various responses in the four spillage categories to a single number. The ratings, which are based on the seriousness of spillage type, are as follows:

Smells of any kind	Faint	1
	Strong	2
Door open spillage	Rarely	1
	Occasionally	2
	Often	4
Closed door spillage	Rarely	3
	Occasionally	4
	Often	5
Spillage over night		6

Applying this rating system to 100 completed surveys, the following was revealed:

Rating of zero - no spillage	3
Ratings of 1 to 4 - minor	65
Rating of 5 to 8 - moderate	21
Rating of 9 or greater - serious	11

The 11 systems rated 9 or greater were examined in detail to assess the causes of the serious spillage.

When the 11 troubled systems were analyzed, the reasons for spillage problems became clear. Five of the systems had outside chimneys, and five of the appliances were located in basements. Five of the flue pipe assemblies had key dampers which were implicated in the reporting of spillage events. One of the systems had 3.4 metres (11 ft) of flue pipe with three 90 degree elbows. Spillage events were associated with slow smouldering fires in seven of the systems and three of them showed deposits of glazed creosote in the firebox. In one house, the total system height (hearth pad to chimney cap) was only 4.6 metres (15 ft) and this was combined with an appliance having a very large loading door. One chimney top was severely affected by wind effects created by trees hanging over the house. These eleven severely troubled systems had far higher statistical incidence of spillage-inducing characteristics than did the less troubled systems in the sample.

Internal Flow Restrictions of Appliances

Test Objectives

The venting system is usually considered the major contributor to spillage since its function is to successfully vent the products of combustion. However, some woodburning appliances have internal restrictions which could inhibit the flow of combustion gases and dilution air, thereby promoting open door spillage. When the appliance loading door is opened, it is desirable that the combustion gases encounter only a minimum of resistance while travelling through the appliance and the remainder of the flow path.

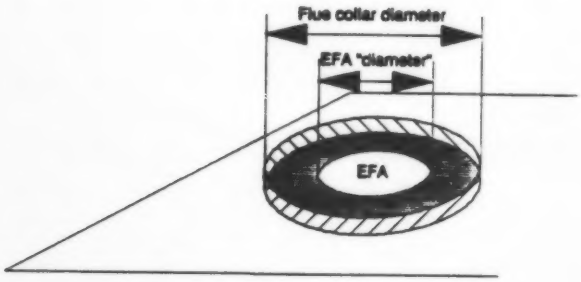
To provide manufacturers with the concept of resistance to flow and a simplified method of measuring it, a device for measuring static pressure and flow through a woodburning appliance was developed. A fan and duct assembly was calibrated and used to draw air through appliances under test. The resulting flow was passed through an orifice plate and pressure taps for measurement. Most of the tests were conducted with the appliance loading doors open. A more detailed description of this device is given in Appendix B.

To help interpret the results from this stove testing device, the concept of equivalent flow area (EFA) was adopted. Equivalent leakage area is the unit of measurement used in the housing field to express the total of all leaks through a

building envelope and is determined by depressurizing the house and measuring the total resulting flow. As it is applied here, the EFA is the size of orifice through which the flow of air through an appliance would pass at a given pressure difference. It represents the appliance's total resistance to flow, expressed as an orifice.

The smaller the measured EFA, the greater the resistance to flow. To further simplify the presentation of the EFA value, it is related to the flue collar diameter (Figure 1) which represents the reference orifice through which gases must flow. This concept of equivalent flue collar diameter is useful because it allows for a quick mental image or interpretation of the stove EFA.

Figure 1
Flue Collar Diameter vs EFA Equivalent Diameter



Test Results

Table 1 shows the results of a portion of the EFA testing conducted during the project. The equivalent diameter value shown in Table 1 is the diameter of an orifice which represents the restriction to flow.

From the laboratory work on EFA testing following observations can be made:

1. As an appliance's open door EFA is decreased, its tendency to be a factor in open door spillage is increased.

2. As an appliance's open door EFA is increased, its tendency to be a factor in open door spillage is decreased.

3. Open door EFA is one of several factors which affect the contribution of the appliance to a wood heating system's tendency to spill combustion products.

Table 1
EFA Test Results of Several Appliances

	Appliance Type	Flue dia. cm	ELA m^2	Equiv. dia. cm	% Dif. %	Door Size width cm	height cm	Door Area cm^2	Door-Flue Ratio
Lakewood Cottager	Non-EPA	15	0.0120	12	-20%	24	24	582	1:3.3
PSG Dynastie	Non-EPA	15	0.0180	15	0	35	29	1029	1:5.8
Regency R6 Large	EPA non-cat	15	0.0126	13	-13%	52	22	1124	1:6.4
Regency R3 Medium	EPA non-cat	15	0.0070	9	-40%	44	20	869	1:5.1
Seefire 900S	EPA non-cat	15	0.0078	10	-33%	37	26	959	1:4.9
Haugh's Cabot Elite	EPA non-cat	15	0.0129	13	-13%	48	21	1011	1:5.7
Haugh's Mini	Non-EPA	15	0.0130	13	-13%	38	21	798	1:4.5
Lakewood Unicorn	Non-EPA	18	0.0205	16	-11%	45	28	1260	1:5.0
Security, BIS	EPA non-cat	18	0.0198	16	-11%	57	32	1815	1:7.1
V.C. Defiant Encore	EPA catalytic	19	0.0187	15	-21%	54	29	1542	1:5.4
Fisher Grandma Bear	Non-EPA	20	0.0221	17	-15%	53	28	1490	1:4.7
Furnace Surefire 201A	Non-EPA	20	0.0206	16	-20%	30	36	1084	1:3.5
Morso	Non-EPA	18	0.0143	13	-28%	52	33	1716	1:6.8
Valley Comfort C31	Non-EPA	15	0.0161	14	-6%	24	25	613	1:3.5

Appliance Heat Transfer

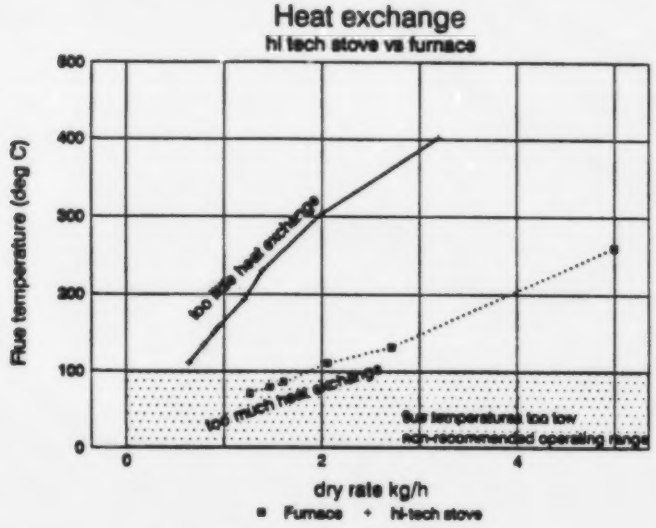
Draft is caused by the temperature difference between the heating system's gas column and the outside air. Appliances with excessive heat transfer can be expected to lower the average temperature reaching the venting system and hinder operating draft. Excessive heat transfer coupled to a high resistance to flow (low EFA) increase an appliance's tendency to spill.

Initially, the laboratory testing concentrated on correlating how an appliance's degree of heat transfer affected the draft produced by its chimney. Using an electric resistance element as a heat source, an attempt was made to link the heat transfer characteristics of a variety of appliances to their tendency to spill. Graphs showing this work are in Appendix D. Unfortunately, the tests did not provide useful results because the electric heat source introduced complex variables which prevented effective comparisons.

Other laboratory work independent of this project involved testing of appliances using the CSA B415 emissions testing procedure. Shown in Figure 2 are the results from two woodburning appliances. The furnace produces much lower stack temperatures than the advanced technology stove. This furnace, like many others,

has a large heat transfer area which was found to hinder the system's operation at low burn rates. Even when burning 2 kilograms of fuel per hour, the furnace extracts so much heat that the temperatures at the base of the stack are still very low, about 100 degrees Celsius. When operating at low burn rates, typical of overnight firing, the furnace temperatures would probably drop into the lower range shown in the figure. This range is not recommended for safe and effective operation.

Figure 2
Outlet Flue Gas Temperature for Two Appliances
With Different Heat Exchange Characteristics

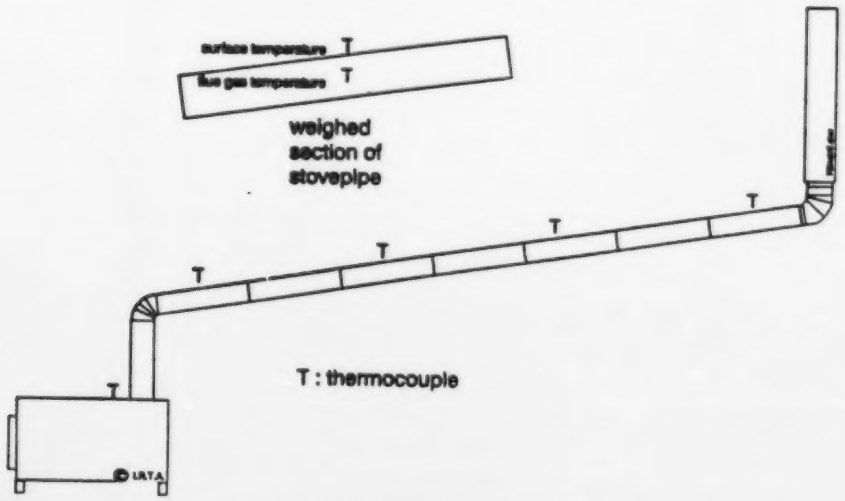


Condensation of Flue Products

Excessive heat transfer may promote the condensation of flue gas components limiting the amount of heat reaching the chimney. The results of laboratory work have shown that creosote condensation occurred most quickly at flue gas temperatures between 60 and 90 degrees Celsius. At flue gas temperatures much lower than 60 degrees, deposits would probably occur in the appliance itself. If flue temperatures throughout the flue could be maintained above 100 degrees Celsius, creosote deposits would be minimized.

Comparative measurements of heat loss from single wall and vented double wall flue pipes indicate that for flue gas temperatures lower than 350 degrees Celsius the vented double wall pipe provides greater heat transfer and cools the gases faster than the single wall pipe. It can be concluded from the tests that the use of either single wall or, preferably, sealed double wall pipe would advisable for systems in which the anticipated flue gas temperature is low.

Figure 3
Condensation Testing Apparatus



Appliance Loading Door Shape and Size

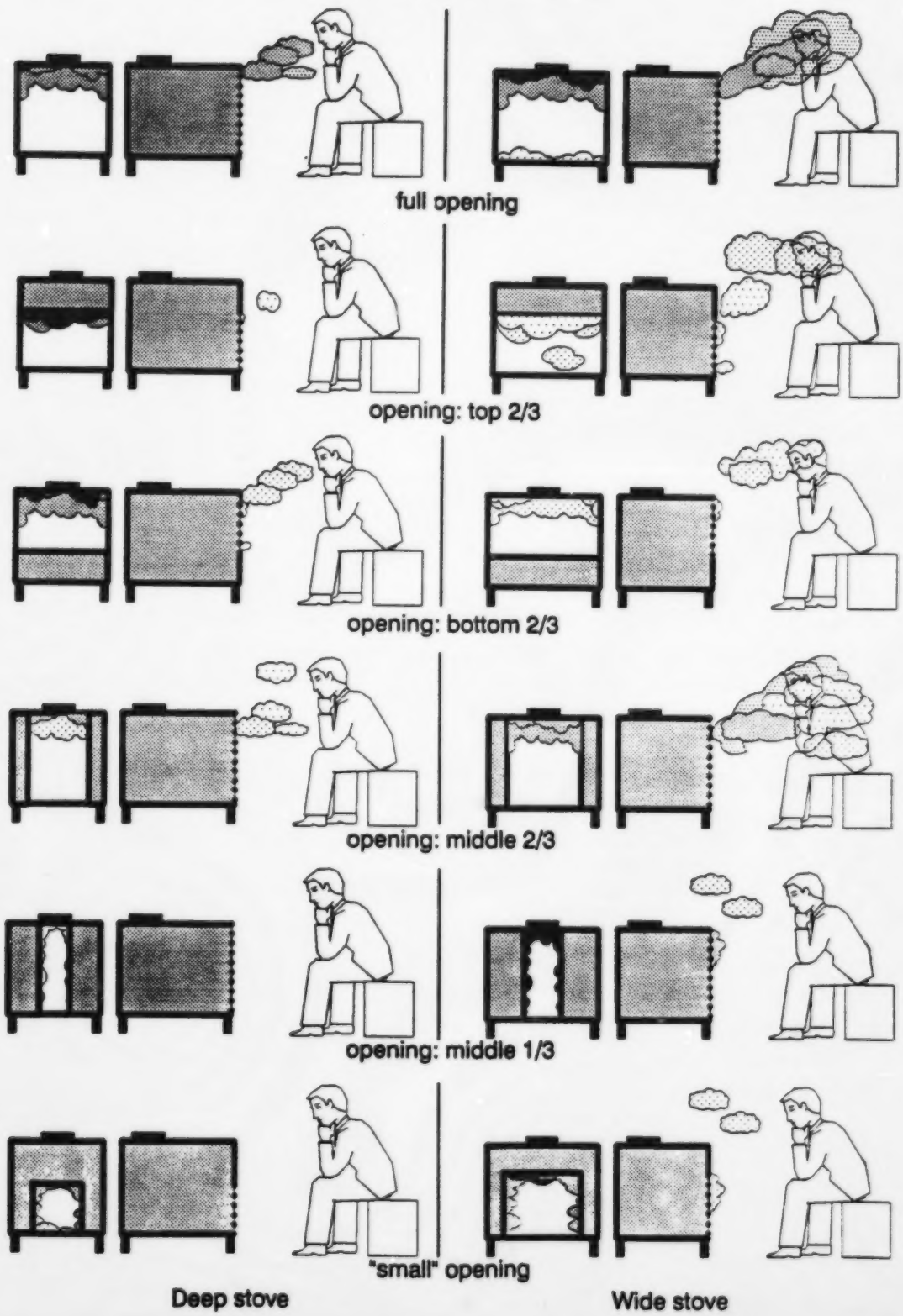
Test Objectives

Results from field monitoring and field surveys confirmed that spillage can occur even under what could be considered acceptable venting conditions. In order to gain further insights into open door spillage, simulations of appliance start-up spillage were conducted in plywood "stoves" of various configurations.

The purpose was to observe spillage patterns from two basic stove types: "wide" and "deep" stoves with no internal baffles. Both test stoves were similar, each with a 0.07 cubic metre (2.5 cu. ft.) combustion chamber and 150 mm (6") flue collar. The smoke test consisted of burning a 30-second smoke candle in the center of each stove's floor area while the stove's outlet was under a 2 Pa depressurization.

The smoke patterns were videotaped to record spillage and allow for later analysis. The spillage patterns at 20 seconds into each test are shown in Figure 5. The observed spillage is qualified visually and categorized as either non-existent, light, medium, or heavy. The two stoves types are shown side by side in order to compare spillage.

Fig 4
Smoke Spillage Simulation



Test Results

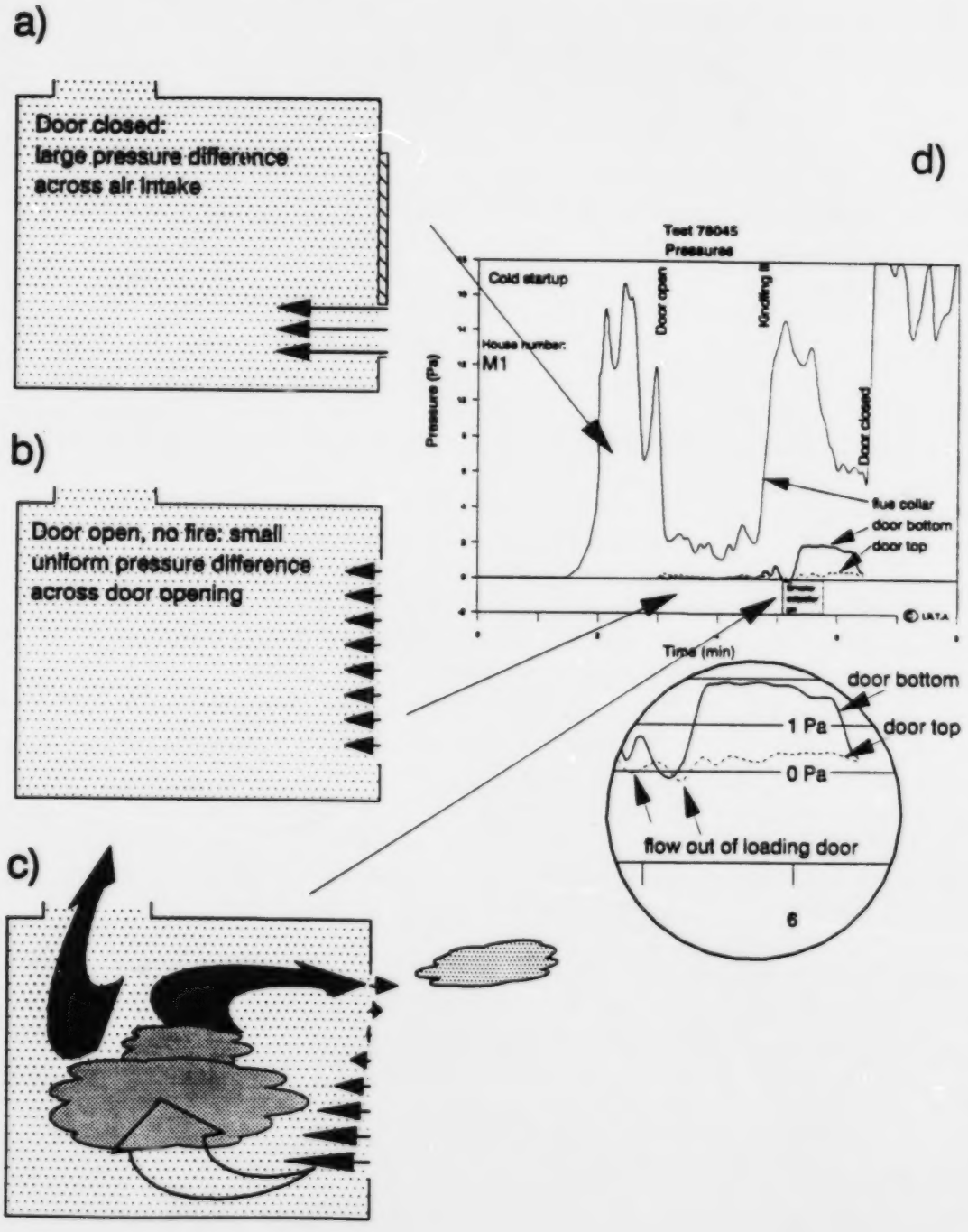
1. There was no spillage with door opening sizes smaller than 450 cm^2 (door-opening to flue ratio of 2.5 to 1)
2. There was light spillage with door opening sizes of 570 to 720 cm^2. (door-opening to flue ratio between 3.1:1 and 3.9:1)
3. With a 835 cm^2 door opening, the deep stove had more spillage with its opening placed at the top rather than at the bottom. (door-opening to flue ratio of 4.6:1)
4. With openings above 1000 cm^2, both appliance types had heavy spillage. (door-opening-to flue ratio higher than 5.5:1)

Observations

The results of the simulated smoke tests, combined with other information from the study and background knowledge of venting allow the following observations to be drawn:

1. Open door spillage is directly related to appliance loading door area. A smaller loading door area increases the pressure gradient across the opening.
2. For the same loading door configuration the "wide" stove with its corresponding larger door opening, will spill more than the "deep" stove.
3. For a given door opening, there will be less spillage if the door opening is at the bottom rather than at the top of the stove. This is probably due to the effect of dynamic pressure of the rising hot gases. In the stove with the opening at the top, convection pushes some of the gases forward at the top of the combustion chamber. When they reach the door opening, the gases continue forward since they are moving faster than the incoming air. In the stove with the opening at the bottom, convection currents are pushing the gases down by the time they reach the door opening. Despite the very low pressure gradient, these gases continue down into the firebox with the slow incoming air rather than out the opening (see Figure 5).

Figure 5
Open Door Spillage



Other Appliance Design Influences

The Critical Firing Rate

Several years ago the combustion laboratories (CCRL) of Energy, Mines and Resources Canada developed a concept that is helpful in describing the behaviour of wood stove fires at low heat output rates. CCRL observed that, as the firing rate is reduced, a point is reached at which there is insufficient heat and turbulence to sustain flaming combustion of the volatile gases rising off the fuel bed. They called this point the critical firing rate[6].

When the combustion rate falls below the critical point, a number of associated effects occur. The heat output from the fire falls abruptly as the gas flames extinguish and the combustible gases pass through the venting system unburned. As temperatures in the system fall, chimney draft also falls, further reducing the firing rate. This sequence of events results in the collapse of effective combustion until only the charcoal glows and the remainder of the fuel smoulders slowly.

Although CCRL described the critical firing rate concept in the context of strategies to reduce emissions through improved combustion design, it has important implications for the understanding of the events which can lead to closed door spillage. One of the patterns that emerged in the survey was closed door spillage occurring overnight after the fire had been turned down or "banked" for the night. Most of the survey respondents who had experienced this form of spillage resolved the problem by opening flue pipe key dampers and combustion air controls to rekindle the fire. During inspections of troubled systems, deposits of glazed creosote on firebox walls were observed, evidence of extremely low firing rates. More than one homeowner, when asked what the fire condition was at the time of the closed door spillage, reported that it consisted of smouldering charred logs which would fall apart when poked. Again, this is evidence of very low firing rates.

In its discussion, CCRL pointed out that, in conventional appliances, the critical firing rate occurs in the same range of heat output as the heat loss from most houses during at least part, and in some cases the majority, of the heating season. This explains why users often set the appliance to operate at the critical firing rate for an overnight burn and inadvertently start the sequence of events leading to the collapse of effective combustion, and increase the risk of spillage during the heating cycle. This effect has been encountered in several systems that were part of the survey and also in systems targeted for remedial measures.

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[6] Emissions From Domestic Wood-fired Appliances: Problems and Potential Solutions, A.C.S. Hayden & R. Braaten, Energy, Mines and Resources, Canada (CANMET); presented at the annual conference of the Canadian Wood Energy Institute, June, 1982.

Energy Momentum

In a research study conducted for CMHC on the influence on fireplace spillage of various forms of combustion air supply, ORTECH described a principle they call "energy momentum", referring to the behaviour of a wood-fired heating system when a fire is burning. Energy momentum is initially created by the heat released from a hot kindling fire and is maintained by the thermal inertia of the system. ORTECH demonstrated that fireplaces incorporating greater mass in the form of firebrick linings produced more energy momentum in the system than fireplaces with unlined steel fireboxes. The concept of energy momentum, as described by ORTECH, can be expanded to more fully explain the dynamic behaviour of the fire itself, as well as the interactive effect the fire condition has on the performance of the total system.

With no fire in the appliance, the system has only the energy momentum produced by the difference in temperature of those system components which are inside the building and the temperature outside. This temperature difference normally produces sufficient draft to cause a small flow of warm room air through the venting system to outside.

When a kindling fire is ignited in an appliance at ambient house temperature (and the system is not backdrafting), the resulting hot gases begin to flow up through the venting system. Part of the heat produced by the burning fuel is absorbed by the unburned fuel, part is absorbed by the mass of the appliance, part is absorbed by venting system components, and the remainder is released to outside from the top of the chimney. All the released energy, except that which is delivered to the appliance surroundings, or is expelled with the flue gases from the top of the chimney, is invested in raising temperatures within the system. It is this invested heat energy that creates energy momentum in the system.

Continuing with the example, if the appliance is now loaded with larger pieces of wood, much of the heat released by the burning kindling is now absorbed by the cold pieces of firewood which have just been added. The heat previously invested in the system by the kindling load provides the energy momentum that sustains draft while the fresh wood begins to catch. When the heat produced by combustion of the new fuel exceeds the amount it absorbs from the burning kindling to sustain combustion, the energy momentum in the system begins to increase as the system components absorb heat. Each time a new load of wood is added to a fire, the energy momentum in the system falls as heat invested in components is released to the flue gases, thereby sustaining the draft needed to rekindle the fire. If the new wood ignites successfully, energy momentum within the system begins to rise again.

The characteristics of every part of the system, including the settings chosen by the operator and firewood used, affect the level of energy momentum produced, its rate of release and rate of recovery. Some types of spillage occurrences reported in the survey, and also observed during field monitoring, can be related to the energy momentum concept. For example, many users reported that open door spillage occurred during low or smouldering fires. At these times, energy momentum within

the system will be low because the fire has not been producing sufficient heat to store in components and any momentum produced early in the fire has been dissipated. Spillage was also commonly reported when the fire was being started, presumably before any significant amount of energy momentum had been established.

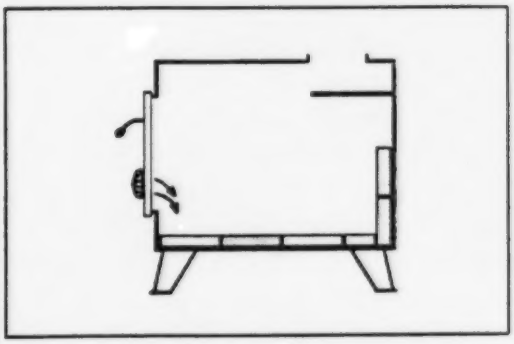
Combustion System Design

Among the woodburning appliances currently in use, there are wide variations in combustion system design. Appliance designers who have concerned themselves with combustion efficiency use a variety of design elements and materials to achieve more complete combustion. These elements include fire brick, cast iron or cast refractory firebox linings, baffles and pre-heated combustion air supplies. While there have always been variations in combustion design, the emergence of environmental concerns related to the airshed impacts of woodburning and the resultant emissions regulations, have radically changed the internal characteristics of woodburning appliances. These characteristics have such a dramatic effect on appliance performance that it has become necessary to further subdivide appliance types into those which meet the emission requirements of the U.S. Environmental Protection Agency (EPA) and those which don't.

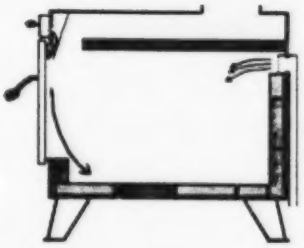
The four general combustion design categories that emerged during the 1970s and early 1980s still exist in EPA certified form. The four categories are updraft, sidedraft, downdraft and catalytic. Of these, the updraft and catalytic types are by far the most common. The following annotated sketches illustrate some of the basic design variations.

Figure 6 Appliance Design

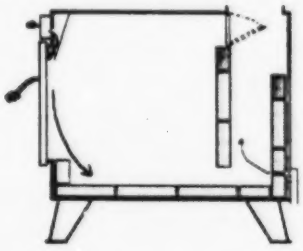
Updraft, non-EPA
This design is representative of many stoves built in the 1970s and early 1980s. They are characterized by the simplicity of the internal design, very little baffling and firebox insulation. Although the design presents little resistance to flow, attempts to reduce the firing rate usually result in smouldering.



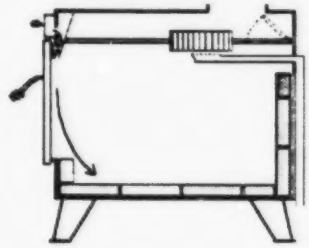
Updraft, EPA
The updraft, non-catalytic EPA certified stove has been common since about 1986. Note the very small exhaust area between the loading door and baffle. This restriction can lead to open door spillage. This design tends to produce fairly high flue gas temperatures which can reduce the likelihood of closed door spillage.



Sidedraft, EPA or non-EPA
This is not a common design but is available in both EPA and non-EPA form. Open door spillage is rare as long as the by-pass damper is opened. In non-EPA form, it can be susceptible to closed door spillage because of smouldering combined with the low exhaust outlet from the firebox.



Catalytic, EPA
EPA certified catalytic stoves can be turned down to very low firing rates and still produce clean exhaust. This feature could lead to closed door spillage because of the associated low flue gas temperature. Spillage will always occur if the loading door is opened when the by-pass damper is closed.



EPA certified appliances, particularly non-catalytics, can be expected to produce higher average flue gas temperatures than conventional appliances. There are two reasons for this characteristic: first, to pass the emissions tests, non-catalytic appliance manufacturers must design a generous minimum combustion air setting to prevent smouldering, and second, firebox insulation, a consistent feature of non-catalytics, reduces heat loss from the firebox and this tends to result in high flue gas temperature. These high flue gas temperatures produce considerable energy momentum within the system and therefore minimize the likelihood of closed door spillage. Open door spillage, however, can be a problem with non-catalytics because most have extensive internal baffling and no by-pass damper.

EPA certified catalytic appliances are generally able to operate at lower firing rates than non-catalytic appliances. These low firing rates and the resultant low flue gas temperatures can lead to low draft and condensation problems in outside, uninsulated chimneys. On the other hand, some characteristics of the new appliances tend to mitigate against operation at extremely low outputs (see discussion of airwash below).

All EPA certified appliances have combustion design characteristics which produce a critical firing rate well below that of conventional appliances. Users are less likely to set EPA certified appliances at or below the critical firing rate because that rate tends to be lower than the average rate of heat loss from average houses.

Glass Doors With Airwash

Glass doors appeared on woodstoves in the early 1980s when heat-resistant ceramic glass first became available. The early designs, however, had no means to keep the products of combustion from condensing on the glass and turning it hazy within a few hours of operation. About 1984, the first glass "airwash" system reached the market. An airwash system brings primary air to the fire through a narrow strip just above the glass. This air flows down the inside surface of the glass and acts as a barrier to combustion gases. The effectiveness of airwash varies from model to model, but the best of them will keep the glass perfectly clear at all but the lowest achievable firing rates.

The combination of glass doors and airwash systems is certainly one of the most significant advancements in residential woodburning since its revival in the early 1970s. The reason is simply that users can see the fire as it burns and this creates the strongest incentive to keep the firing rate high enough to prevent the glass from clouding over.

Glass airwash systems simplify the promotion of good firing technique among householders. Instead of explaining in great detail the strategies for building and maintaining clean-burning, and therefore hot fires, wood heat retailers and others involved in advising the public can give simple firing instructions and introduce the expectation of clear glass. Once users expect the glass to be clear, they will either learn to keep the glass clear or seek advice on what they are doing wrong.

The overall effect of airwash systems is to keep the average temperatures throughout the appliance and venting system higher, increasing energy momentum and reducing the likelihood of closed door spillage.

Outdoor Air Supplies - A Discussion

Some housing technologists, wood heating technicians and code authorities believe that spillage from woodburning systems can be reduced or eliminated by providing a supply of outdoor air to the appliance. This outdoor air is usually supplied either directly to the combustion chamber or indirectly in the form of a

make-up air supply linked to, or in close proximity to the appliance. Research conducted for CMHC by ORTECH, into the spillage sensitivity of factory-built fireplaces under a range of indoor and outdoor pressure regimes, revealed that providing outdoor air is not a simple or effective cure for spillage, and that some designs could create a fire hazard.

The research showed that indirect, make-up type air supplies connected to a circulation chamber around the appliance firebox supplied air only when the room pressure was lower than the outside pressure at the duct weatherhood. At a room pressure of -5 Pa, the maximum house depressurization rate recommended in the CSA F326 ventilation standard[7], the outdoor air duct flow was only half of the fireplace flue flow rate at low burn and about one third the flow rate at high burn. Although the make-up air supply can help to modify the effects of powerful exhaust ventilators on room depressurization, their equivalent leakage area is between 15 and 25 percent of the leakage area of tight houses. At normal house pressures, this type of air supply is insufficient to provide the air requirements of many woodburning appliances.

The ORTECH work also showed that air supplies routed from outside directly to the appliance combustion chamber could supply the total air requirements after the system had reached operating temperature, provided the firebox was sealed tightly from the room. At fire start-up, however, it was necessary to leave the loading door ajar to supply enough air to ignite the wood. Two key findings from the research would appear to serve as cautions against the widespread use of direct combustion air supplies. Firstly, these direct air supplies can reverse flow direction if the weatherhood is exposed to negative pressure in excess of chimney draft. The air supplies could be reversed in the laboratory at 15 to 20 Pa outside depressurization. This level of depressurization can be exceeded when wind effects around the building cause low pressure zones. In fact, pressures many times higher than 20 Pa have been recorded on the leeward side of houses during high winds. The reversal in these ducts results in the flow of hot combustion gases toward the weatherhood and the attendant risk of overheating adjacent combustibles. Secondly, the research showed that smoke leakage can occur, even when the appliance has tightly sealed doors, if the room becomes excessively depressurized - in one case, smoke leaked from the joints between factory-built chimney sections.

Outdoor air supplies, either direct to combustion chamber or indirect supplies to the living space, are not recommended in this report as appropriate remedial measures for smoke spillage problems in woodburning systems. Good system design, component selection and proper operation have been shown to be more reliable ways to mitigate spillage problems. Houses which may experience intermittent episodes of excessive depressurization when exhaust-only ventilators are operated should be provided with a whole-house make-up air system.

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[7] Canadian Standards Association: CAN-F326-1991, Residential Mechanical Ventilation Systems

Observations

The Categories of Spillage Events

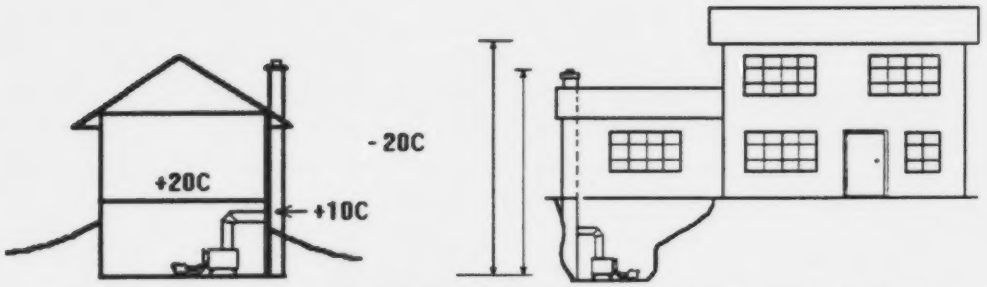
When data from the random survey is combined with results from the laboratory testing, the categories of spillage events, their causes and effects can be stated in simplified form, as follows.

Cold Backdraft

Cause 1: House Stack Effect Exceeds Standby Chimney Draft

When the negative pressure created by house stack effect exceeds the standby draft produced by the chimney when there is no fire in the appliance, a cold backdraft will result. These conditions are often present in systems in which an uninsulated chimney runs up the outside of a house and the appliance is located in the basement, below the house neutral pressure plane. This condition is also possible, even with an inside chimney, if the effective stack height of the house exceeds the height of the chimney.

Figure 7 The Mechanisms of Cold Backdraft



Left: flue gases being excessively cooled in an uninsulated, outside chimney.
Right: chimney stack height shorter than house stack height.

Cause 2: Pressure Induced

A cold backdraft can be wind induced when chimney height, location and surroundings combine to place the top of the chimney under positive pressure. Reversal leading to a cold backdraft can also be initiated by house depressurization caused by the operation of a powerful exhaust ventilator. Once started, the cold backdraft will be sustained if the appliance is located below the house's neutral pressure plane.

Effect 1: When there is no fire in the system, a cold backdraft fills the room/house with the unpleasant smell of creosote.

Effect 2: If a fire is lit in a system in cold backdraft, 100 percent of the combustion products will spill into the room.

Open Door Spillage

Cause 1: Appliance Restriction

A restrictive combustion system (low EFA), or closed by-pass damper can cause open door spillage.

Cause 2: Appliance Loading Door Area and Relationship to Flue Collar

An appliance which has a large loading door area relative to its flue collar or internal EFA can promote open door spillage. The spatial relationship between the loading door area and the flue collar can also play a role, ie. flue collars located at or below the top of the loading door have been linked to open door spillage.

Cause 3: Restrictive Venting System

An excessively long flue pipe assembly or one with several elbows promotes open door spillage. Flue pipe key dampers which are not set to the open position before the loading door is opened produce open door spillage. Venting systems which are blocked or partly blocked cause open door spillage.

Cause 4: Low Flue Gas Temperature

Low draft caused by excessive cooling of flue gases or by low, smouldering fires is a significant factor in open door spillage.

Cause 5: Adverse Pressures

Adverse pressures within the house created by competing exhaust ventilators can oppose chimney draft and cause open door spillage. Adverse winds which cause positive pressure at the top of the chimney can also cause open door spillage.

Effect: Spillage of a portion of combustion products, ie. smoke roll-out.

Closed Door Spillage

Cause 1: Smouldering Combustion

Low, smouldering, flameless combustion is a consistent factor in closed door spillage events. Smouldering combustion is usually the result of extremely low

combustion air control settings as set by the operator or the result of the action of a bi-metallic air control operator.

Cause 2: Venting System Restriction

Closed or near-closed flue pipe key dampers are associated with closed door spillage. The resultant low fire and low draft combine with the restriction offered by the key damper to produce spillage. Blocked or severely restricted flue pipes or chimney flues can also produce closed door spillage.

Cause 3: Adverse Pressures

Severe adverse pressures within the house created by competing exhaust ventilators can oppose chimney draft and cause closed door spillage. Adverse winds which cause positive pressure at the top of the chimney can also be a factor in closed door spillage, although usually in combination with smouldering combustion.

Effect 1: Spillage From Available Openings

Spillage of a portion of combustion gases from available openings in the appliance and flue pipe is a form of closed door spillage associated with a combination of the listed causes. It occurs when the venting system is unable to fully exhaust the combustion products.

Effect 2: Combustion Oscillations (Puffing)

Puffing of smoke from available openings is a different phenomenon from the partial spillage of combustion gases in Effect 1. Puffing usually occurs during the first hour or two after loading when a large volume of combustible gas is being produced and when combustion air supply is severely restricted to produce smouldering combustion, commonly by a bi-metallic air control operator. Puffing can be in the form of a single small explosion in the combustion chamber or, more commonly, a series of puffs caused by oscillating pressure waves within the appliance and venting system. Puffing is initiated by the abrupt ignition and resulting expansion of combustible gases.

Hot Backdraft

A hot backdraft is defined as 100 percent spillage of combustion gases sometime after proper venting has been established. No evidence of hot backdraft was found during the research, although it is theoretically possible. A hot backdraft would most likely be caused by an extremely powerful competing exhaust ventilator combined with a smouldering fire condition.

4. The Human Factor

Respondent Profile

The majority of the 100 people who's wood heating systems were evaluated as part of the survey lived outside urban areas and considered themselves serious woodburners. When asked if wood was their main or secondary heating fuel, 66 said it was the main fuel. 81 of the users claimed that the appliance was used at least 50 percent of the time during the winter months; 54 claimed it was used 100 percent of the time. 68 percent of those surveyed used more than six face cords (nominal 4' x 8' x 16") of wood per heating season. Ten people used the appliance for cooking and five used it for heating water in addition to space heating. 90 people had had their chimney cleaned at least once in the past year; half of these had it cleaned twice or more.

The first spillage-related question in the interview portion of the survey was "Have you ever noticed any of the following smells when your appliance is in operation?: a faint woodsy smell, a strong wood smoke smell, the smell of hot steel or the smell of creosote". Only 19 people reported no smells of any kind, but of these, 15 reported some form of spillage when asked more detailed questions later in the interview. This response pattern is noteworthy because it reflects what most wood heating retailers and chimney sweeps know: that people take some pride in their ability to heat with wood effectively and they are also inclined to be happy with their wood heating system, even if an observer might see several things about it that could be improved. These responses may also suggest a degree of tolerance to wood smoke in the home. The responses of most of the people who admitted spillage problems indicate that some amount of spillage is considered normal and acceptable. Only a few of the participants showed any real concern about the fact that their system smoked into the house under certain conditions.

Of those who experienced spillage problems, a large majority seemed to feel they had some understanding of the causes or conditions under which spillage occurred; very few had no idea why their system spilled. By far the most commonly reported conditions that increased spillage when the loading door was opened were low fires during mild weather. 18 indicated that low or smouldering fires seemed to be linked to spillage; 12 reported that mild, damp, cloudy or overcast weather (referred to by several participants as "heavy air"), was a main factor in spillage events; and 10 reported that the combination of smouldering and mild weather led to spillage. Eight admitted that spillage occurred when they forgot to open the flue pipe key damper or appliance bypass damper before opening the door, and seven people claimed that wind was an important factor in open door spillage. The remaining participants reported a variety of causes, including dirty flue pipes and chimney, and when the load of wood is placed too close to the front of the firebox. A

total of 85 of the survey participants had experienced some amount of open door spillage.

Closed door spillage was reported by 31 percent of the participants. Of these, 7 associated spillage with smouldering fires, one associated it with mild weather, and 5 linked the combination of smouldering and mild weather to the spillage. Five believed that closed door spillage episodes had to do with windy days. Three reported that the spillage occurred when the chimney needed cleaning. Two homeowners linked spillage with the operation of other exhaust ventilators causing negative pressure in the house: in one case by a kitchen stove top exhaust and one by the operation of another woodburning appliance. One system targeted for monitoring and remedial measures was affected by a house ventilation system which placed the furnace room under negative pressure.

User Responses to Spillage Events

The 31 respondents who reported closed door spillage were asked what, if anything, they did at the time to stop the spillage of smoke. The most common responses to the question had to do with increasing the burn rate or other ways of heating the chimney. Eight respondents said they opened the air control and 5 respondents burned some newspaper. These responses seem to demonstrate an understanding that a low or smouldering fire makes a system more susceptible to spillage. Four respondents indicated that they reduced flow restrictions by opening flue pipe key dampers or appliance by-pass dampers. Again, these responses indicate an understanding of the mechanisms that lead to spillage. Other responses included cleaning the chimney and flue pipes (4), closing the air control (3), opening the loading door (1), blow in the combustion air opening (1), opening a window (1), and turning off the exhaust fan (1). Three respondents did not know what to do and so did nothing.

When a woodburning appliance begins to spill with the loading door closed, the experience can be unsettling, if not frightening, yet more than half of those who experienced it had some understanding of the mechanisms involved and knew of ways to stop the spillage. Overall, the majority of users surveyed display confidence in their ability to control spillage when it occurs. While there is some understanding of the observed cause and effect relationships related to closed door spillage, the field monitoring part of the research showed that users tend to have little if any understanding of the design characteristics that make their systems prone to spillage in the first place. Given the number and complexity of possible contributing factors influencing spillage, it is not surprising that householders cannot diagnose design problems with their wood heating systems. This would support the argument that professionals such as wood heating appliance installers, retailers and chimney sweeps are needed to diagnose the causes of combustion spillage and recommend remedial measures.

5. Testing of Remedial Measures

Test Objectives

A number of systems were targeted for field monitoring and to test proposed remedial measures. After identifying and recruiting householders for involvement in the project, the systems were inspected and householder interviewed using the survey documents. Various levels of instrumentation were installed and the systems were monitored in the as-found condition. After approximately one week of as-found testing, remedial measures were undertaken and monitoring was repeated.

The objectives of the field monitoring was to complement the field survey program by monitoring the performance of heating systems known to have spillage problems. Remedial measures aimed at eliminating or reducing the spillage were then tested to determine their effectiveness.

Results of Remedial Measure Testing

A total of 34 systems were field tested at various levels of detail, from full instrumentation to interviews and instruction. The following brief summaries of the diagnostics, remedial measures and results from selected systems are just a small sample, but they are representative of the types of problems encountered, measures taken, and results.

Reports on Four Representative Systems

System # I2: Flow Resistance and Firing Technique

System:	Furnace, 2.6 m (8.5') flue pipe with two 90 degree elbows, two 45s and chimney base tee, 5.2 m (17') inside metal chimney
Problem:	Severe open door spillage; 18 events in 10 days
Diagnosis:	Flue pipe restrictions, furnace adjustments, firing technique
Remedial Measures:	Replaced flue pipe assembly with one having only two 45 degree elbows; adjusted barometric draft control to maximum permitted value of 15 Pa (0.06"wc); instructed user on proper firing technique, ie. lots of newspaper and kindling to start, smaller fires in mild weather, remove ashes more often, look for firebrick to be tan in colour and steel parts to be light to dark brown, never black and shiny.
Results:	No spillage events in 6 days of monitoring. Homeowner reports problem resolved almost entirely. Can avoid spillage easily.

System # P7: Leaking Chimney, Cold Backdraft and Open Door Spillage

System: Woodstove installed in basement, 1.5 m (5') flue pipe with one 90 degree elbow; 5.2 m (17') outside concrete block chimney with nominal 8" x 8" clay tile liner.

Problem: Severe cold backdraft (house smelled of creosote); severe open door spillage.

Diagnosis: Large vertical cracks in block chimney shell; suspect that outside chimney/basement installation would have been susceptible to cold backdraft; leakage just made it much worse.

Remedial Measures: Replaced damaged chimney with inside 650°C metal chimney.

Results: One spillage event recorded in 5 days of test (user claims the event was caused by operator error); owner reports no cold backdraft, no open door spillage.

System # I3: Severe Cold Backdraft

System: Woodstove installed in basement, 1.5 m (5') flue pipe with one 90 degree elbow; 6.2 m (20') outside masonry chimney with nominal 8" x 12" clay tile liners.

Problem: Severe, chronic cold backdraft which made lighting a fire very difficult.

Diagnosis: Oversized, outside chimney being cooled, negative pressure in basement causing cold backdraft; chimney was not code height above the roof and adjoining roof level is higher; may be some influence from other exhaust ventilators (three bathroom exhausts and kitchen exhaust).

Remedial Measures: Added 1.2 m (4') to chimney height, reline existing chimney with 150 mm (6") stainless liner and insulate around liner.

Results: Owner reports that the cold backdraft is much less severe and easier to correct with hair drier, but the system will still reverse when there is no fire in the stove. The fact that the chimney top is lower than the effective stack height of the house is likely responsible for the continued cold backdraft. The mechanism is discussed and illustrated in Section 3, Mechanisms of Venting Failure, Observations.

System # P6: Firing Technique

System: Sidedraft woodstove with by-pass damper installed on main floor, 2.2 m (7') single wall flue pipe straight up into cathedral ceiling-mounted factory-built chimney 2.8 m (9') in length. Note: this system appeared "perfect" from a spillage resistance point of view.

Problem:	Several events of overnight closed door spillage. Had also experienced combustion oscillations (smoke puffing). Homeowner was becoming afraid to use the stove because of unpredictable spillage events.
Diagnosis:	Evidence of extreme smouldering, ie. glazed creosote in firebox, the form of a charred log remained in the cold firebox. User seemed unaware of proper firing technique and at a loss as to the cause of the problem.
Remedial Measures:	Gave the householders careful instructions on firing technique and strategy for maintaining hotter fires. Demonstrated fire kindling technique. Installed stack thermometer and provided instructions for use.
Results:	No events of smoke spillage since instructions were given. Homeowners are far more confident in the use of the system: "The thermometer really helped. Now I know that I can run it much hotter without fear of overheating anything".

Discussion

The field testing work on targeted problem systems confirmed many of the findings of the survey. Improper firing technique was a significant contributor in over half of the systems tested; relatively inexpensive measures such as straighter flue pipe assemblies helped to correct problems in about 30 percent of the systems; about 10 percent of the systems were severely troubled and needed extensive and, in some cases, expensive remedial measures. The findings from all of the field testing work are reflected in Section 6, Conclusions and Section 7, Planning and Diagnostic Tools.

6. Conclusions

1. Combustion spillage from wood heating appliances is a common occurrence; almost all woodburning systems spill combustion products to some degree. The frequency and duration of spillage events varies widely among the systems surveyed and tested, from rare wisps of smoke to chronic and dangerous spillage events.

2. The most common form of spillage occurs when the appliance loading door is opened at fire start-up or re-loading. The duration and severity of most open door spillage events can be controlled by the user and are dependent to some extent on the tolerance of inhabitants to wood smoke in the house.

3. Spillage which occurs when the loading door is closed is considered more serious and was experienced at least once by almost one-third of survey respondents.

4. The frequency, duration and severity of spillage is affected by the design of the appliance, the design of the venting system, the way the appliance is operated and the pressure regime in which the system is operated

5. There are five appliance design characteristics that influence spillage:
   - loading door opening area relative to flue collar area, ie. the smaller the ratio, the less prone to spillage;
   - internal flow restrictions, ie. the less restriction, the less prone to spillage;
   - the spatial relationship between the top of the loading door and the flue collar, ie. the higher the flue collar relative to the top of the loading door, the less prone to spillage;
   - combustion system design, ie. the more able the appliance is to operate at low firing rates while sustaining flaming combustion, the less prone to spillage; and,
   - ability of the user to see the fire burning, ie. glass doors with airwash systems tend to make wood heating systems less prone to spillage.

   The over-sizing of appliances for the space to be heated can also be a factor by increasing the likelihood of low firing rates and smouldering.

6. The frequency and duration of spillage is strongly effected by the average temperature within the venting system, ie. the higher the average temperature, the less prone the system will be to spillage. The conservation of input flue gas heat to the venting system can be achieved by:
   - locating chimneys within the house envelope

- insulating the area between the flue and chimney shell
- avoiding elbows or offsets in chimneys
- minimizing or eliminating elbows in flue pipe assemblies
- keeping flue pipe assemblies short, ie. less than 2 metres
- using sealed double-wall flue pipes
- avoiding the use of flue pipe key dampers
- avoiding the use of barometric draft controls, where possible

7. User behaviour is a significant factor in spillage, both by inducing spillage and in preventing spillage. Systems which would be considered technically "perfect" from a combustion spillage point of view spilled because of the way they were operated, and systems that had many technical or design characteristics which could be expected to make them spillage-prone did not spill because of careful and knowledgeable operation by the user.

8. By far the most common user practice which induces spillage is to load the appliance and set the controls in such a way as to cause the fire to smoulder. Other user inputs that induce spillage are:
   - failing to open flue pipe key dampers before opening the loading door,
   - failing to open appliance by-pass dampers before opening the loading door,
   - failing to clean appliance internal passages, and
   - failing to clean the venting system.

9. User practices can be successfully changed to make wood heating systems more resistant to spillage by informing users of the cause and effect relationships that apply and by providing relatively simple instructions on appliance firing technique.

10. Users do not have enough knowledge to diagnose the causes of spillage related to system design or pressure dynamics. The services of trained technicians are needed to assist users in diagnosing and correcting these types of spillage problems.

11. Adverse pressures acting on wood heating systems operating on natural draft can be a significant factor in combustion spillage. Pressures which are adverse to the effective venting of flue gases can be caused by:
    - the stack effect of the house acting on an appliance installed below the house neutral pressure plane,
    - competing exhaust ventilators which cause house depressurization,
    - wind effects acting on the top of the chimney.

12. The stack effect of a house is not normally the primary cause of spillage but can be a contributing factor in combination with other system characteristics such as an uninsulated chimney installed outside the house envelope.

13. Although house depressurization caused by powerful exhaust ventilators can be a factor in spillage events, it was found to be a significant factor in only five of the 134 systems studied.

14. System design characteristics, component selection, and operating technique are the primary factors in the majority of spillage problems. More than half of all spillage problems can be prevented by making relatively subtle changes to the system and/or by helping users operate the systems properly.

15. The remedial measures tested during this project were successful in making woodburning systems less susceptible to spillage under normal operating conditions. However, exhaust only ventilators such as high-volume kitchen exhausts and house ventilation systems which supply no make-up air can depressurize houses to the extent that even the most spillage-resistant systems may suffer venting failure. Mechanical make-up air systems interlocked to such high volume exhausts may be required to prevent excessive house depressurization.

16. The minimum chimney height requirements in building codes are not sufficient in all cases to prevent-wind induced adverse pressures from acting on the top of chimneys.

7. Planning and Diagnostic Tools

Assessment of System Features

The table below summarizes the findings from the survey/inspection, laboratory research and field testing components of the project. The findings are presented in practical rather than scientific form.

Table 2 Assessment of System Features

Appliance

Promotes Spillage	Resists Spillage
Too large for space heat loss	Properly sized for space heat loss
Unlined combustion chamber	Lined or insulated combustion chamber
No combustion system	EPA certified combustion system
Large door opening area vs flue collar	Moderate to small door opening
Leaky construction	Sealed construction
Large heat exchanger	Moderate to small heat exchanger
Firebox exhaust lower than door opening	Firebox exhaust higher than door opening
Solid doors	Glass doors with air wash system

Flue Pipe

Promotes Spillage	Resists Spillage
Sized different than appliance flue collar	Size matched to appliance flue collar
Assembly includes elbows	Assembly straight to chimney
More than 2 metres in length	Less than 2 metres in length
Assembly has key damper	No restrictions to flow
Assembly loose and leaky	Assembly reasonably well sealed

Chimney

Promotes Spillage	Resists Spillage
Chimney flue is not insulated	Chimney flue is insulated
Located up outside wall	Installed inside house envelope
Flue size different than flue collar size	Flue matched to appliance flue collar
Flue has offsets	Flue is straight
Total system height less than 4.5 metres	Total system height more than 4.5 metres
Chimney height less than code requires	Chimney height exceeds code requirements
Chimney not clear of roof	Chimney clears top of roof
Leakage causes cooling and dilution	Chimney is well-sealed

House/Setting

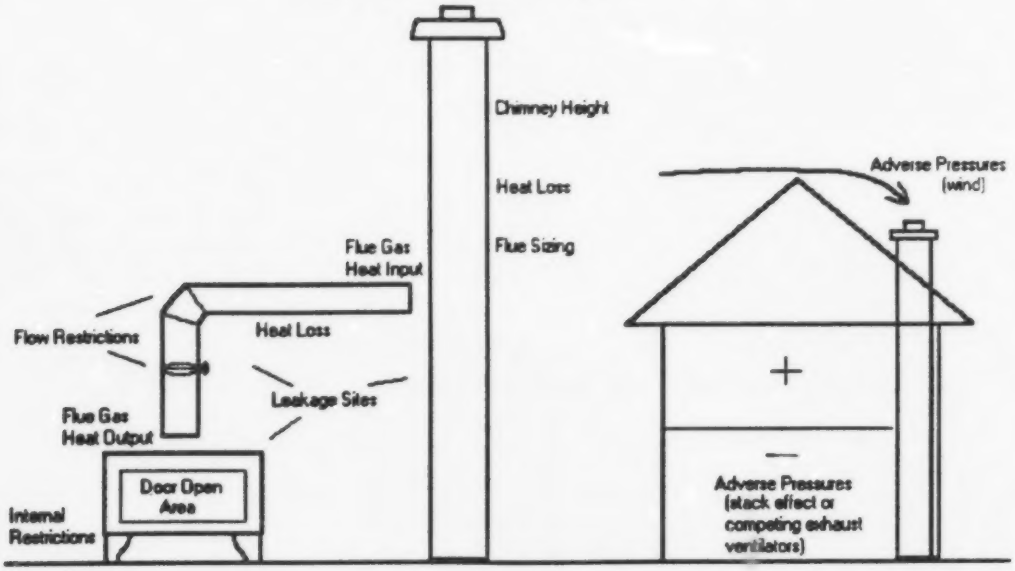
Promotes Spillage	Resists Spillage
Has high volume exhaust ventilators	No high volume exhaust ventilators
Appliance is located below neutral plane	Appliance is located above neutral plane
House set low compared to nearby features	House is clear of wind obstructions

Appliance Operator

Promotes Spillage	Resists Spillage
Tolerant to wood smoke smell	Intolerant to wood smoke
Routinely operates appliance at low output	Knows how to avoid smouldering
Misuses flue pipe key damper	Takes care in use of flue pipe key damper
Inexperienced wood burner	Experienced wood burner

Summary of Spillage Diagnostics

Figure 8 Spillage Diagnostics



Summary of Remedial Strategies

Table 3 Remedial Strategies

	Problem Diagnosis	Remedial Action
Chimney Top Temperature	Outside chimney being chilled	1. Enclose in chase 2. Reline and insulate 3. Install inside chimney
	Chimney flue oversized or undersized	1. Reline to correct size 2. Replace with chimney of correct size
	Excessive flue pipe heat loss	1. Replace with sealed double-wall pipe 2. Re-locate appliance or chimney to shorten flue pipe run 3. Replace 90 deg elbows with 45s
	Low flue gas temperature from appliance	1. Instruct user to build hotter fires - avoid smouldering 2. Instruct user on influence of bi-metallic operator 3. Split wood smaller, use drier wood 4. Replace oversized appliance with one of correct size 5. Replace conventional appliance with one of advanced technology
Flow Restrictions	Elbows in flue pipes	Replace 90 degree elbows with 45s
	Flue pipe key dampers	1. If possible, remove key damper 2. Instruct user in proper use of damper
	Creosote build-up or blocked breech	Clean chimney or reconstruct breech
	Appliance by-pass dampers	Instruct user on proper use of by-pass
External Influences	Chimney top affected by wind and nearby obstacles	1. Increase chimney height 2. Remove obstacles 3. Specialized chimney cap may help
	Adverse pressures	1. Eliminate competing exhaust ventilator 2. Install make-up air supply 3. Instruct user to avoid operating competing exhaust-only ventilators while woodburner is operating

Summary of Anti-Spillage Messages for Users

After a thorough inspection of the heating system and the house to identify the design or mechanical causes of spillage, and after remedial measures have been taken to increase resistance to spillage, the user(s) should be instructed on techniques they can use to reduce spillage. The following techniques are organized into three categories: understanding and correcting a cold backdraft, techniques to raise the average flue gas temperature, and maintenance required to prevent restrictions and to keep the appliance operating properly.

1. Cold Backdraft Syndrome

Explain stack effect in houses briefly, ie. "The air in the house is warm compared to outside and this creates low pressure in the basement and higher pressures in the upper levels as the warm air rises. If the chimney runs up the outside of the house, allowing the flue to get cold, and the appliance is installed in the basement, the house becomes a better chimney than the chimney and uses it as an air intake." Point out that if the chimney were installed inside the house, its draft would usually exceed the stack effect of the house.

To correct a cold backdraft without causing spillage:
- open a basement window to relieve pressure before lighting fire
- use a hair drier in chimney cleanout

To correct a backdraft but risk some spillage:
- burn some newspaper in chimney cleanout or appliance

2. Techniques for Raising Average Venting System Temperatures

Here's what to do:

1. Use plenty of newspaper when lighting a fire; 6 - 10 sheets crumpled.
2. Use plenty of small pieces of dry kindling.
3. When starting a fire, set the air controls fully open.
4. Once kindling is charred and flaming brightly, add a few pieces of intermediate kindling - do not smother the kindling fire.
5. Never add just one piece of wood at a time.
6. Never reload the appliance until the room or house temperature has begun to fall.
7. Operate the appliance in cycles - one cycle is the time between loading on a coal bed and its burning down to a coal bed of the same size.
8. When loading on a coal bed, always add at least three pieces, and preferably six or seven.
9. If you want to produce less heat, use smaller pieces, not fewer pieces.

10 In spring and fall to take the chill off the house, use the flash fire technique, ie. several smallish pieces crisscrossed.
11. For a longer cycle, such as over night, use larger pieces placed compactly.
12. Never allow excess ash to build up in the firebox - many stoves should have some ash removed each morning.
13. Install a flue pipe thermometer about 450 mm (18") above the flue collar. To determine the correct operating temperatures, do this: after a hot initial burn, fire the appliance at the minimum rate which sustains flaming combustion while monitoring the thermometer reading. From then on, never allow the temperature to fall below this level until the fire reaches the coal bed phase.
14. Fire each new load for between 20 and 45 minutes at full output, until the wood is flaming brightly and is well charred.

Here's what users should expect to see:

1. If there are no flames, something is wrong - when wood burns it should be flaming until only charcoal remains.
2. If there are firebricks in the appliance firebox, they should be tan in colour, never black.
3. Steel parts of the firebox should be light to dark brown, never black and shiny.
4. When things are working properly, users should expect instant ignition of a new load of wood - the bottom pieces should be flaming by the time the door is closed.
5. If the stove has a glass door with airwash, it should be clear.
6. If the stove has a glass door without airwash, it will be hazy, but should never be totally black.
7. The exhaust coming from the top of the chimney should be clear or white. A plume of blue or grey smoke indicates smouldering and probably low system operating temperatures.

3. Anti-Spillage Maintenance

1. Inspect the appliance, flue pipes and chimney regularly to monitor ash, soot and creosote build-up, and clean as necessary to prevent restrictions.
2. Check the internal passages of the appliance to ensure that components such as insulation have not shifted from their intended position.
3. Check and clean catalytic combustors regularly; use a vacuum to remove ash.
3. Check door, glass and cleanout gaskets to be sure they are sealing properly; the objective is not to keep the unit as "airtight" as possible, but to ensure that combustion air enters only where it is intended to enter.